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ALGORITHM DEVELOPMENT & EXPERIMENTAL EVALUATION OF BLIND EQUALIZERS FOR RAPIDLY VARYING CHANNELS WITH ANTENNA ARRAYS

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13. ABSTRACT (Maximum 200 words)

RESEARCH FOCUSED ON DEVELOPING AND TESTING EFFICIENT ALGORITHMS FOR EXPLICIT MODELING AND BLIND ESTIMATION OF TIME-VARYING COMMUNICATION CHANNELS, AND THE RESULTING SELF-RECOVERING ANTENNA RECEIVERS AND EQUALIZERS IN RAPIDLY FADING MOBILE BATTLEFIELD SCENARIOS. ESTABLISHED THAT FINITELY PARAMETERIZED BASIS EXPANSIONS RENDER SINGLE-INPUT SINGLE-OUTPUT (ISIO) TIME-VARYING (TV) CHANNELS EQUIVALENT TO MULTIVARIATE TIME-INVARIANT (IT) CHANNELS WITH INPUTS FORMED BY MODULATING A SINGLE INPUT WITH THE BASES (J2,J3).

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This is to certify that research under ARO grant No. DAAG55-98-1-0336
was performed until 9/99 when the award to the University of Virginia
ended. Renewed funds under this grant were awarded directly to the
University of Minnesota where the PI is currently employed as a professor
of the Electrical and Computer Engineering Department. Research until
9/99 focused on the development and testing of efficient algorithms for
modeling and blind estimation of time-varying communication channels,
and the resulting self-recovering antenna receivers and equalizers in
rapidly fading mobile battlefield scenarios.

Briefly, we have developed basis expansion models for single-input
single-output (SISO) time-varying (TV) channels and proved them equivalent
to multivariate time-invariant (TI) channels with inputs formed by
modulating a single input with the bases. SISO-TV fading channels
capture phase noise, oscillator drifts, Doppler effects caused by
relative motion between transmitters and receivers, and varying
multipath propagation encountered with mobile wireless links in the
battlefield. They give rise to time- and frequency-selective
intersymbol interference (ISI) which has been traditionally modeled
via random (Rayleigh or Rician) channels; however, by establishing
links with existing physical channel measurements, we have discovered
that deterministic Fourier bases expansions are well motivated for
modeling rapidly fading mobile communication channels when multipath
propagation caused by a few dominant reflectors gives rise to
(Doppler induced) linearly varying path delays. Our algorithms estimate
Doppler frequencies blindly using cyclic statistics and determine the
channel orders relying upon rank properties of a received data matrix.
By complementing channel (or Doppler) diversity with temporal, or, spatial
diversity (available with oversampling or multiple antennas), we have derived
blind estimators of TV channels along with direct equalizers. Two deterministic
blind equalization algorithms have been derived: one determines the channels
first and then the equalizers, whereas the other estimates the equalizers
directly. The equalizers are TI, multivariate, zero-forcing, and lend
themselves to optimally weighted and adaptive extensions. We have also
proved that exploitation of the input's whiteness reduces the amount of
spatio/temporal diversity (only two sensors) needed to identify blindly
TV channels and mitigate their effects using minimum mean-square
error equalizers.

Over the last six months (3/99-9/99) we exploited transmitter-induced
redundancy to develop novel channel estimation and symbol recovery
approaches for blind identification and equalization of time- and
frequency-selective channels where the time variation is modeled
deterministically by a basis expansion. The resulting statistical
algorithm enables the usage of a single antenna, dispenses with channel
disparity conditions of existing approaches, and allows channel order
overestimation. In addition, new deterministic algorithms for
generalized OFDM systems were introduced which produce reliable
estimates with few data points at high SNRs. Simulations illustrate
the approaches developed.

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Research tasks accomplished (02/98 - 02/99)

Research so far has focused on developing and testing efficient algorithms for: (i)explicit modeling and blind estimation of time-varying communication channels, and the resulting (ii)self-recovering antenna receivers and equalizers in rapidly fading mobile battlefield scenarios. Our recent results are detailed in journal [J1-J4] and conference [C1-C4] publications.

In a nutshell, we have established that finitely parameterized basis expansions render single-input single-output (SISO) time-varying (TV) channels equivalent to multivariate time-invariant (TI) channels with inputs formed by modulating a single input with the bases [J2,J3]. SISO-TV fading channels are of paramount importance both for commercial as well as for military communications because they capture phase noise, oscillator drifts, Doppler effects caused by relative motion between transmitters and receivers, and varying multipath propagation encountered with mobile wireless links in the battlefield [J1,J3]. They cause time- and frequency-selective inter-symbol interference (ISI) which has been traditionally modeled via random (Rayleigh or Rician) channels; however, by establishing links with existing physical channel measurements, we have shown that deterministic Fourier bases expansions are well motivated for modeling rapidly fading mobile communication channels when multipath propagation caused by a few dominant reflectors gives rise to (Doppler induced) linearly varying path delays. Our algorithms estimate Doppler frequencies blindly using cyclic statistics and determine the channel orders relying upon rank properties of a received data matrix [J3]. By complementing channel (or Doppler) diversity with temporal, or, spatial diversity (available with oversampling or multiple antennas), we have derived

blind estimators of TV channels along with direct equalizers under with minimal (persistence-of-excitation) assumptions on the input and the bases [J3,J4]. Two deterministic blind equalization algorithms have been derived: one determines the channels first and then the equalizers, whereas the other estimates the equalizers directly. The equalizers are time-invariant, multivariate, zero-forcing, and lend themselves to optimally weighted and adaptive extensions [J4]. We have also proved that exploitation of the input's whiteness reduces the amount of spatio/temporal diversity (only two sensors) needed to identify blindly TV channels and mitigate their effects using minimum mean-square error equalizers [C1]. Sensitivity to order and model mismatch have been studied briefly [J4].

Research tasks to be accomplished (03/99 - 2,0001)

Future work on the algorithmic tasks of our proposal will focus on:

- performance analysis of the channel estimators especially when model perturbations due to synchronization effects and Doppler frequency drifts are present;

- development of online fully-adaptive algorithms for estimating both the bases frequencies as well as the equalizer coefficients;

- performance evaluation in terms of error probability for the zero-forcing equalizers and simulation-based comparisons with the mean-square error equalizers;

- exploitation of input redundancy in the form of time-varying precoding filterbanks, for estimating TV channels with antenna arrays (without oversampling or deployment of multiple antennas preliminary results reported in [C2-C4] are very encouraging);

More than 60% of our future research efforts will concentrate on the experimental tasks described in the original time-table of our proposal (revised and updated below):

```
                                  March 99   Oct. 99   May 00   May 01
development of fully adaptive
algorithms, performance analysis  ---------------->
and extensive simulations


testbed integration and
preliminary testing                         ---------------->


Real data evaluation                           ------------------->


development of algorithms relying                    --------------->
on transmit- and receive-diversity


Algorithm implementation                             --------------------->
data and testbed experiments
```

ARO DAAG55-98-1-0336 supported publications: 02/98-02/99

Journal papers

[J1] F. Gini and G. B. Giannakis, "Frequency Offset and Symbol Timing Recovery in Flat Fading Channels: A Cyclostationary Approach," *IEEE Transactions on Communications*, vol. 46, pp. 400-411, March 1998.

[J2] G. B. Giannakis, "Channel Estimation and Equalization," *IEEE Signal Processing Magazine*, A. O. Hero, Editor for Highlights of Statistical Signal and Array Processing, pp. 21-64, vol. 15, no. 5, September 1998.

[J3] G. B. Giannakis and C. Tepedelenlioglu, "Basis Expansion Models and Diversity Techniques for Blind Equalization of Time-Varying Channels," *Proceedings of the IEEE*. vol. 86. pp. 1969-1986, October 1998.

[J4] H. Liu and G. B. Giannakis, "Deterministic approaches for blind equalization of time-varying channels with antenna arrays," *IEEE Transactions on Signal Processing*, vol. 46, no. 11, pp. 3003-3013, November 1998.

Publications in Conference Proceedings

[C1] C. Tepedelenlioglu and G. B. Giannakis, "Blind equalization of time-varying channel using second-order statistics," *Proc. of Wireless Com. Workshop*, pp. 138-143, San Diego, CA, March 1998.

[C2] A. Scaglione, S. Barbarossa, and G. B. Giannakis, "Self-recovering equalization of time-selective fading channels using redundant filterbank precoders," *Proc. of Digital Signal Proc. Workshop*, Bryce Canyon, Utah, August 9-12, 1998.

[C3] C. Tepedelenlioglu and G. B. Giannakis, "Blind estimation and equalization of time- and frequency-selective channels using filterbank precoders," *Proc. of 32nd Asilomar Conf. on Signals, Systems, and Computers*, Pacific Grove, CA, Nov. 1-4, 1998 (to appear).

[C4] C. Tepedelenlioglu and G. B. Giannakis, "Deterministic Blind Estimation of Time- and Frequency-Selective Fading Channels using Filterbank Precoders," *Proc. of 2nd Workshop on Signal Proc. Advances in Wireless Communications*, Annapolis, MD, May 1999 (to appear).